Institutional Members: CEPR, NBER and Università Bocconi

WORKING PAPER SERIES

Can Comparative Advantage Explain the Growth of US Trade?

Alessandro Cunat and Marco Maffezzoli

Working Paper n. 241

July 2003

IGIER – Università Bocconi, Via Salasco 5, 20136 Milano –Italy
http://www.igier.uni-bocconi.it

Can Comparative Advantage Explain the Growth of US Trade?[1]

Alejandro Cuñat
LSE and CEPR
a.cunat@lse.ac.uk

Marco Maffezzoli
Università Bocconi and IGIER
marco.maffezzoli@uni-bocconi.it

This draft: July 30th, 2003

[1]A previous version of this paper appeared as IGIER Working Paper #220. We are grateful to Don Davis, Tim Kehoe, Matt Slaughter, Tony Venables, Jaume Ventura, David Weinstein, and Kei-Mu Yi for valuable discussions; seminar participants at Bocconi, CEP, Geneva, Mainz, the New York Fed, Nottingham, SED 2003, and Vigo for helpful comments; and Kwok-Tong Soo for superb research assistance. All errors remain ours.

Abstract

We present a dynamic comparative advantage model in which moderate reductions in trade costs can generate sizable increases in trade volumes over time. A fall in trade costs has two effects on the volume of trade. First, for given factor endowments, it raises the degree of specialization of countries, leading to a larger volume of trade in the short run. Second, it raises the factor price of each country's abundant production factor, leading to diverging paths of relative factor endowments across countries and a rising degree of specialization. A simulation exercise shows that a fall in trade costs over time produces a non-linear increase in the trade share of output as in the data. Even when elasticities of substitution are not particularly high, moderate reductions in trade costs lead to large trade volumes over time.

Keywords: International Trade, Heckscher-Ohlin.

JEL codes: F1, F4.

1 Introduction

One of the most remarkable economic phenomena of the last 40 years is the large increase of the world's trade volume. International economists tend to agree about lower import tariffs being the natural explanation to this fact, since the second half of the 20th century has been a period of worldwide trade liberalization. Figure 1 illustrates this idea by plotting the time paths of a world's average import tariff and the US GDP share of its trade volume with non-OPEC countries for the period 1960-1997.[1] While the former has fallen by almost a 50% (from 0.16 to 0.09), the latter has almost trebled (from 0.06 to 0.18). Econometric evidence by Baier and Bergstrand [1] also supports the idea that the reduction of tariff-rates is by far the most important contributor to the rise of the trade share in GDP.[2]

On the theoretical side, however, linking the fall of import tariffs to the rise of world trade does not seem to be such a trivial exercise. As Yi [23] points out, any attempt to explain the growth of the world's trade volume on the basis of falling trade barriers with any of the standard trade models available in the literature (comparative advantage, increasing returns, Armington assumption) is challenged by the magnitudes of these variables. Generating a three-fold increase in the volume of trade's share in GDP with just a 7 percentage-point fall of the average tariff requires unrealistically high elasticities of substitution between goods.[3] Besides, the relationship between import tariffs and trade volume is far from being linear, as the standard models would suggest. Figure 2 plots the US trade share in GDP against the world's average tariff. Notice the increase in the volume of trade from the mid-70s to the early 90s despite the approximately constant tariff over the same period. Alternative explanations to the growth of world trade have not been entirely successful at accounting for the increasing trade volume. Yi [23], for example, explains these puzzles on the basis of vertical specialization only occurring after trade

[1] The world's average import tariff is based on tariffs (i.e. import duties over imports) from 35 countries, both developed and developing. See Clemens and Williamson [3]. We are grateful to Jeff Williamson for kindly sharing these data. Data on volumes of trade come from the IMF's DOTS database.

[2] "New trade" theory links increased similarity of countries' incomes to higher trade shares (see Helpman [11]), but the empirical evidence in Baier and Bergstrand [1] and Hummels and Levinsohn [14] does not seem to lend strong support to this view. Bergoeing and Kehoe [2] calibrate a "new trade" theory model in the spirit of Helpman and Krugman [12] and Markusen [17], obtaining mixed results about the ability of the model to match the impressive growth of intra-OECD trade in the second half of the 20th century.

[3] Yi [23] calculates that standard trade models need an elasticity of above 10 or 13 for observed tariff reductions to generate an increase of the trade share in GDP proportional to what we see in the data. Estimated and calibrated elasticities are usually between 2 and 3.

costs have reached a critical value. His model, however, falls short of explaining an important share of the growth in the volume of trade.

This paper goes back to comparative advantage to address these issues. We profit from an obvious yet important consideration that has been ignored so far in this context, namely that both trade liberalization and the growth of trade have got a time dimension. We produce a model based on standard models in the areas of international trade (the Heckscher-Ohlin model) and economic growth (the Ramsey model). We argue that a large non-linear increase in the volume of trade in the face of a moderate reduction in trade barriers over time is quite a natural fact once one allows for a dynamic response on the factor accumulation side, even when elasticities of substitution are low.

In a nutshell, the argument goes as follows: a fall in trade costs has two effects on the volume of trade. First, for given relative factor endowments, it raises the degree of specialization of countries, leading to a larger volume of trade in the short run. Second, it raises (lowers) the factor price of each country's abundant (scarce) production factor, leading to diverging paths of relative factor endowments across countries and a rising degree of specialization over time. This creates an additional effect on the future volume of trade that adds to the static and dynamic effects of future reductions in trade costs. From a qualitative point of view, the observed sequence of reductions in trade costs over time brings about a non-linear response of the trade share in GDP. From a quantitative perspective, the dynamic response of the export share in GDP when we allow for factor accumulation is three times larger than in the static trade model.

Our arguments are based on the idea that comparative advantage, and therefore international trade, is driven to a certain extent by cross-country differences in relative factor endowments. In this respect, a recent stream of empirical research has highlighted the relevance of factor endowments for trade, even between rich countries.[4] At the same time, this does not rule out other reasons for trade, such as technological differences, increasing returns, or vertical specialization. In fact, any of these elements could be combined with our stylised Heckscher-Ohlin model to provide a more realistic view of international trade.[5]

[4]See, among other references, Davis and Weinstein [6], [7], [8], and Romalis [19]. Notably, Davis and Weinstein [7] show that, against popular belief, factor endowments are quite important for North-North trade. They suggest that, for the median country in their ten-country OECD sample, between one third and one half of its factor trade is with other countries in the same sample.

[5]Romalis [19], for example, combines Heckscher-Ohlin and "new trade" features in a model with transport costs. In fact, the static trade part of our model can be understood as a particular

A sketch of the Heckscher-Ohlin model with many goods and trade costs that we use can be found in Mundell [18]; Dornbusch *et al.* [10] provide an elegant formalization of the continuum of goods; Romalis [19] introduces trade costs into the model. There is a vast number of dynamic Heckscher-Ohlin models in the literature, starting with Stiglitz [21]. Some recent references comparing neoclassical growth under autarky and free trade are Ventura [22] and Cuñat and Maffezzoli [5]. In comparison with these models, we depart from the rather unrealistic autarky/free trade dichotomy by introducing a trade cost that can change over time. This key feature enables us to uncover some new insights on the effects of trade integration when the latter takes place over a long time span.

The rest of the paper is structured as follows: Section 2 presents our analytical setup, which is used in Section 3 to analyze the link between trade integration and relative factor endowment divergence. Section 4 discusses the effects of the fall of trade costs over time on the export share in GDP. Section 5 concludes.

2 The Model

This section presents the dynamic trade model we use for studying the long-run effects of trade integration and technical change. The dynamic component is a standard Ramsey model, into which we integrate a Heckscher-Ohlin comparative advantage framework.

2.1 Consumption and Capital Accumulation

Assume the world has two countries, Home and Foreign, denoted by $j = H, F$. Each country is populated by a *continuum* of identical and infinitely lived households, each of measure zero, that can be aggregated into a single country-level representative household. There are two internationally immobile factors, capital K and labor L. For simplicity, we assume that the labor endowment does not respond to changes in factor prices. Each country produces a nontraded final good, which is used for both consumption C and investment I. The representative households' preferences over consumption streams can be summarized by the following intertemporal utility

case of his. Yi [23] thinks of vertical specialization as the outcome of Ricardian features, but these may be substituted or complemented by Heckscher-Ohlin features as well.

function:[6]

$$U_{jt} = \sum_{s=t}^{\infty} \beta^{s-t} \ln\left(C_{js}\right), \tag{1}$$

where β is the subjective intertemporal discount factor. The representative households maximize equation (1) subject to the intratemporal budget constraint

$$P_{jt}\left(C_{jt} + I_{jt}\right) = w_{jt} L_{jt} + r_{jt} K_{jt}, \tag{2}$$

where P_j is the price of the final good. Factor prices are taken as given by the representative household. The capital stocks evolve according to the following accumulation equation:

$$K_{jt+1} = (1-\delta) K_{jt} + I_{jt}. \tag{3}$$

The first order conditions

$$\beta C_{jt}(r_{jt}/P_{jt} + 1 - \delta) = C_{jt+1}, \tag{4}$$

$$K_{jt+1} = \left(w_{jt}/P_{jt}\right) L_j + \left(r_{jt}/P_{jt} + 1 - \delta\right) K_{jt} - C_{jt}, \tag{5}$$

and the usual transversality conditions are necessary and sufficient for the representative household's problem. A recursive competitive equilibrium for this economy is characterized by equations (4)-(5) and the equations that characterize the static trade equilibrium.

2.2 Static Trade Equilibrium

Assume all markets are competitive. The final good is produced with a continuum of intermediates $z \in [0,1]$, with the following Cobb-Douglas production function:

$$Y_j = \kappa \exp\left[\int_0^1 \ln x_j(z)\, dz\right], \tag{6}$$

where $x_j(z)$ denotes the quantity of intermediate good z used in the production of the final good Y_j in country j, and κ is a positive constant.[7] Demand for intermediate goods is given by $x_j(z) = \frac{P_j Y_j}{p_j(z)}$, where P_j is the aggregate price index

$$P_j = \kappa^{-1} \exp\left[\int_0^1 \ln p_j(z)\, dz\right]. \tag{7}$$

[6] In general, we denote aggregate variables with capital letters.

[7] κ is just used for normalization purposes and plays no major role in the model.

Intermediate goods are produced using capital and labor with the following Cobb-Douglas technologies:

$$y_j\left(z\right) = \phi_j k_j\left(z\right)^z l_j\left(z\right)^{1-z}, \tag{8}$$

where $y_j\left(z\right)$ denotes the quantity of intermediate good z produced in country j; ϕ_j denotes country-specific factor efficiency levels; and $k_j\left(z\right)$ and $l_j\left(z\right)$ denote, respectively, the capital and labor allocated to the production of intermediate good z in country j. Capital-labor intensities are increasing in z. Technologies are identical across countries, but for the exogenous factor augmenting coefficients ϕ_j. The assumption of unitary elasticities is meant to show how our model's dynamic dimension can lead to large long-run trade volumes even when we 'cripple' the static model's ability to do so.[8]

In contrast with the final good, intermediate goods can be traded. Trade in intermediates, however, is assumed not to be frictionless: $\tau > 1$ units of a good must be shipped from the country of origin for one unit to arrive in the country of destination. ($\tau - 1$ gives a measure of the trade cost. That is, $\tau = 1$ corresponds to free trade.) This is the classical "iceberg" assumption, due to Samuelson [20]. We can think of trade costs as both transport costs and barriers to trade. Concerning the latter interpretation, we abstract from any revenue they might produce. For simplicity, we assume balanced trade: $P_j Y_j = r_j K_j + w_j L_j$.

Let us assume $K_H/L_H > K_F/L_F$, so that Home (Foreign) has a comparative advantage in capital-intensive (labor-intensive) goods. In general, the model's equilibrium is characterized by a range of very capital-intensive goods and a range of very labor-intensive goods produced exclusively by Home and Foreign, respectively; a range of nontraded goods produced by both countries; and factor prices such that $w_H/r_H > w_F/r_F$. We choose $p_F\left(0\right) = 1$ as the numeraire. Given ϕ_j, K_j, L_j, and τ, the unknowns of the model are w_j, r_j, P_j, and z_j. The two cut-off values z_H, z_F, $0 \leq z_H < z_F \leq 1$, divide the range $[0, 1]$ in the three ranges mentioned above (see Figure 3):

1. For $z \in [0, z_H)$, z is produced exclusively by Foreign, and exported to Home. Therefore $p_H\left(z\right) = \tau p_F\left(z\right)$, and $p_F\left(z\right) = \phi_F^{-1} Z\left(z\right) r_F^z w_F^{1-z}$, where $Z(z) = z^{-z}\left(1-z\right)^{z-1}$. Market clearing implies $y_H(z) = 0$, and $p_F\left(z\right) y_F(z) = P_H Y_H + P_F Y_F$.

2. For $z \in [z_H, z_F]$, z is produced in both Home and Foreign, and nontraded.

[8]The assumption that each sector's capital share equals its index ($\alpha\left(z\right) = z$) is admittedly strong, but very helpful to solve the model.

Therefore $p_j(z) = \phi_j^{-1} Z(z) r_j^z w_j^{1-z}$. Market clearing implies $p_j(z) y_j(z) = P_j Y_j$.

3. For $z \in (z_F, 1]$, z is produced exclusively by Home, and exported to Foreign. Therefore $p_H(z) = \phi_H^{-1} Z(z) r_H^z w_H^{1-z}$, and $p_F(z) = \tau p_H(z)$. Market clearing implies $p_H(z) y_H(z) = P_H Y_H + P_F Y_F$, and $y_F(z) = 0$.

We can solve for the unknowns from the definition of P_j and the following system of equations:[9]

1. Factor market clearing conditions:

$$\int_0^1 \frac{\partial \phi_j^{-1} Z(z) r_j^z w_j^{1-z}}{\partial w} y_j(z)\, dz = L_j, \tag{9}$$

$$\int_0^1 \frac{\partial \phi_j^{-1} Z(z) r_j^z w_j^{1-z}}{\partial r} y_j(z)\, dz = K_j. \tag{10}$$

2. Marginal commodity conditions:

$$\phi_j^{-1} Z(z_j) r_j^z w_j^{1-z} = \tau \phi_{-j}^{-1} Z(z_j) r_{-j}^z w_{-j}^{1-z}. \tag{11}$$

   Given factor prices, the marginal commodity conditions imply there is a range of commodities that are not worth shipping from one country to another despite comparative advantage. This is due to the price wedge the trade cost introduces between countries.

3. Numeraire:

$$p_F(0) = 1 = \phi_F^{-1} w_F. \tag{12}$$

The system has no analytical solution, and needs to be solved numerically.[10]

If $(K_H/L_H)/(K_F/L_F)$ is 'too small' relative to τ, countries will not trade and the equilibrium will be like under autarky, with $z_H = 0$ and $z_F = 1$. In this case, from the factor and good market clearing conditions,

$$\frac{w_j^a}{r_j^a} = \frac{K_j}{L_j}, \tag{13}$$

[9] By Walras Law, one of these conditions is redundant.

[10] Unlike in Dornbusch *et al.* [9], there is no easy way to summarize the equilibrium conditions as the intersection of a few nicely behaved schedules.

where the index a distinguishes autarky equilibrium prices from trade equilibrium prices. For the autarky equilibrium to be sustainable, it must be true that at autarky prices transport costs make it pointless to ship goods across countries. That is, the marginal commodity conditions implied by equation (11) must not hold for $z \in (0,1)$:

$$\phi_F^{-1} r_F^a \leq \tau \phi_H^{-1} r_H^a, \tag{14}$$
$$\phi_H^{-1} w_H^a \leq \tau \phi_F^{-1} w_F^a. \tag{15}$$

Thus, if $(w_H^a/r_H^a) / (w_F^a/r_F^a) = (K_H/L_H) / (K_F/L_F) \leq \tau^2$, autarky will take place. If, on the other hand, $(K_H/L_H) / (K_F/L_F) > \tau^2$, autarky will not be sustainable and countries will trade.

2.3 Steady State

When countries trade,

$$\frac{r_H/P_H}{r_F/P_F} = \frac{\phi_H}{\phi_F} \tau^{\frac{z_H^2 - z_F^2 + 2(z_F - 1)}{z_F - z_H}}. \tag{16}$$

It is easy to see that $\frac{z_H^2 - z_F^2 + 2(z_F - 1)}{z_F - z_H} < 0$. Thus, for $K_H/L_H > K_F/L_F$ and $\phi_H = \phi_F$, $r_H/P_H < r_F/P_F$. Given the assumption that β and δ are equal across countries, the steady state is characterized by the same interest rate for both of them: $r_j/P_j = r/P \equiv \frac{1}{\beta} - 1 + \delta$. Hence, the model *cannot* yield a steady state in which countries trade, if technologies are identical across countries. Since we want to depart from the autarky-vs-free trade thought experiment, let us impose enough structure so as to have an initial steady state with some trade. Assume $\phi_H > \phi_F$. Then $r_H/P_H = r_F/P_F$ if

$$\tau^{\frac{z_H^2 - z_F^2 + 2(z_F - 1)}{z_F - z_H}} = \frac{\phi_F}{\phi_H}. \tag{17}$$

Thus, provided $\phi_H > \phi_F$, we may find a steady state in which countries trade.[11] The system of equilibrium equations and the condition $r_H/P_H = r_F/P_F$ can be solved numerically for K_H, K_F, z_H, and z_F. A similar procedure enables us to solve for the ϕ_j's that generate a particular steady-state distribution of capital stocks such that

[11] There are other ways to generate different steady-state capital-labor ratios. *E.g.,* one can assume that the investment good may have a different price relative to the consumption good across countries. In terms of the intratemporal budget constraint,

$$P_{jt} \left(C_{jt} + \gamma_j I_{jt} \right) = w_{jt} L_{jt} + r_{jt} K_{jt},$$

where $\gamma > 0$. Cross-country differences in γ may be justified in terms of taxation, institutions, etc.

$K_H/L_H > \tau^2 K_F/L_F$. Numerical explorations suggest that both of these procedures are remarkably robust and generate unique results.

2.4 Solution Procedure

The recursive structure of our problem guarantees that the solution can be represented as a couple of time-invariant policy functions expressing the optimal level of consumption in each region as a function of the two state variables, K_H and K_F. These policy functions have to satisfy the following functional equations:

$$\beta C_j \left(K'_H, K'_F\right) \left(r'_j/P'_j + 1 - \delta\right) = C_j \left(K_H, K_F\right), \tag{18}$$

where $K'_j = \left[\left(w_j/P_j\right) L_j + \left(1 - \delta + r_j/P_j\right) K_j - C_j \left(K_H, K_F\right)\right]$, and the factor prices w_j/P_j and r_j/P_j are obtained by numerically solving the appropriate equilibrium conditions. The policy functions have to generate stationary time series in order to satisfy the transversality conditions. To solve equation (18) numerically, we apply the Orthogonal Collocation projection method described in Judd [15]. The Appendix describes our computational strategy in detail.

We choose parameter values that yield an initial steady state in which Home's trade share in GDP and the trade cost approximate, respectively, the US trade share (0.06) and the world average import tariff (1.17). Following Cooley and Prescott [4], we set $\beta = 0.96$ and $\delta = 0.048$ - standard values in the quantitative macroeconomics literature which implicitly assume that the unit time period is a year. We assume $L_H + L_F = 2$. We choose $\kappa = 0.15$, which implies an autarky steady-state world capital stock $\bar{K} = 2$ when $\phi_j = 1$. We fix $\tau_0 = 1.17$ and numerically solve for the ϕ_j's that yield a trade share in GDP equal to 0.06 for Home. The resulting coefficients are $\phi_H = 1.09$ and $\phi_F = 0.93$, which imply $\bar{K}_H + \bar{K}_F = 2$, and $\left(\bar{K}_H/L_H\right) / \left(\bar{K}_F/L_F\right) = 1.84 > \tau_0^2$. (We choose a symmetric situation such that $\bar{K}_H = L_F$ and $\bar{K}_F = L_H$.)

3 Trade Integration and Factor Accumulation

To study the effects of a reduction in trade costs, we assume the world is in the steady state described above, and let τ fall to $\tau_1 = 1.16$ suddenly and permanently. Figure 4 displays the time paths of real per-capita income, consumption, investment, and capital for both countries, as percentage deviations from the original steady state. (The first ten years correspond to the original steady state.) On impact, income per capita increases by 0.03 percentage points at Home and by 0.04 points in Foreign.[12] This effect is due to the static gains from trade integration, which reduces the price wedge between countries. Countries can now exploit their comparative advantages better for given factor endowments. That is, both Home and Foreign find it optimal to reduce the range of goods they produce and exchange a wider range of commodities. This enables both of them to "consume" more intermediate goods and thus produce more of the final good.

The static effect is quite small in comparison with the long-run effect, since the dynamics leads to a remarkable process of long-run divergence in capital-labor ratios. To understand the mechanics of the exercise, let us look at the time path of factor prices in terms of the final good in Figure 5. Notice that right after the fall in τ interest rates diverge, rising in country H and falling in country F. This raises the incentive to delay consumption and accumulate capital in country H, whereas the opposite happens in country F. This is what causes the initial upward (downward) jump of investment, and the initial downward (upward) jump of consumption in country H (country F).[13]

Why do interest rates react as they do after a fall in τ? Home ceases to produce the most labor-intensive goods it used to produce, since they become cheaper to import from Foreign. This implies capital and labor need to be reallocated from labor-intensive towards capital-intensive goods. In this case, full employment requires the use of lower capital-labor intensities, which imply a higher marginal productivity of capital, and thus a higher r_H. A symmetric argument leads to a lower r_F. Figure 6 shows that the range of non-traded goods shrinks immediately after the fall in τ: z_F falls, *i.e.* country F ceases to produce its most capital-intensive goods, and z_H rises, *i.e.* country H stops producing its most labor-intensive goods. Notice that both countries' shares of trade in income, $V_H = 2z_H$ and $V_F = 2\left(1 - z_F\right)$, increase.[14]

The different reaction of interest rates implies that investment increases in country H and decreases in country F. Home (Foreign) raises (reduces) its capital-labor ratio and drives the interest rate back to its steady-state level over time. This leads to an increasing difference in their capital-labor ratios, and reinforces their respec-

[12] The static effect is so small that it cannot be read off Figure 4.

[13] The cross-country interest rate differential is actually very small, being no grater than 0.08 percentage points: the presence of moderate transaction costs might be enough to prevent international capital flows.

[14] Kehoe and Ruhl [16] show that actual episodes of trade liberalizations increased trade along both the intensive (more trade in the same goods) and the extensive margins (trade in new goods). This empirical evidence is in line with our model's predictions.

tive patterns of comparative advantage, reducing the range of nontraded goods even more, and raising the share of trade in GDP. In fact, the dynamic response of the two countries' trade volumes is much larger than the static one. For example, 50 years after the fall in τ, the increase in the trade share is more than double as large as the short-run (static) increase.

It is worth noting that both countries gain from trade integration in terms of welfare. A comparison of their utility levels with and without the fall in the trade cost shows that both countries achieve a higher level of utility in the new scenario. Although the long-run income per capita level of Foreign falls, the fact that it can attain a higher level of consumption in the first periods after the change in τ compensates for the discounted long-run losses in consumption. On the other hand, Home experiences an initial fall in consumption, but is more than compensated by the discounted future gains.

Notice that the result on long-run income and consumption divergence depends on the assumption that one of the two factors is not accumulable. A similar model with two accumulable factors would predict diverging relative factor endowments and growing volumes of trade over time, but not necessarily cross-country income per capita divergence. Trade liberalization would produce an interest rate differential in favor of each country's relatively abundant factor. Within each country, therefore, investment would be reallocated towards the abundant factor, exacerbating cross-country relative factor endowment differences.

4 A Fall in Trade Costs over Time

Yi [23] argues that the nonlinear growth of the trade share in GDP is hard to explain by standard trade models on the basis of falling trade barriers, since these have not decreased that much over the same time period. The discussion in the previous section suggests that a non-linear increase in the volume of trade in the face of a protracted reduction in trade barriers is quite a natural fact once one takes into account the dynamic response on the factor accumulation side. In our model, a fall in trade costs raises the volume of trade immediately, but also leads to diverging paths of relative factor endowments through its effect on factor prices. This creates an additional effect on the future volume of trade, that adds to the static effect of subsequent reductions in trade costs.

We perform a simulation exercise with our dynamic trade model to illustrate this argument. We feed the time path of the world average import tariff into our model, and compare the predicted time paths for the North's trade share in GDP with that of the US. For this purpose, however, we first have to decide whether the fall in the trade cost over time is unexpected or anticipated. This is a matter of relevance, given that permanent changes in the trade cost lead to changes in steady states. We assume that trade liberalization is a decision about the future path of τ, which is made at time 0 and is known by economic agents. The process that determines the time path of τ after trade liberalization is agreed is assumed to be

$$\tau_{t+1} = (1-\theta)\,\bar{\tau} + \theta\tau_t + e_{t+1}, \tag{19}$$

where $\bar{\tau}$ denotes the long-run value for τ, and e is an error term.[15] Given the observed time path for τ, we use nonlinear least squares to estimate θ ($\hat{\theta} = 0.96$) and $\bar{\tau}$ ($\bar{\tau} = 1.08$). The model fits remarkably well: all coefficients are highly significant.[16] These estimates and equation (19) enable us to obtain the "expected" time path $\hat{\tau}$. Any differences between the expected and observed time paths are treated as unexpected changes in the trade cost.

We assume that the world is in the steady state associated with $\tau_0 = 1.17$ and $\left(\bar{K}_H/L_H\right) / \left(\bar{K}_F/L_F\right) = 1.84$, which implies a trade share in GDP equal to 0.06 for Home, and that at time 0 a trade liberalization agreement is reached, whereby the future time path of τ is determined according to equation (19). Figure 7 plots the actual (solid line) and predicted (dotted line) time paths of the US trade share in GDP. Our simulation approximates the actual time path for the US trade share very accurately. The predicted export share rises over time due to both the change in the long-run value $\bar{\tau}$ and to the variation in τ_t. The fall in $\bar{\tau}$ implies a change in the steady states of countries, and therefore triggers a process of long-run relative factor endowment divergence. The successive reductions in τ_t cause a sequence of increases in the trade share (through both the static and dynamic mechanisms discussed in the previous section) that build upon the effect generated by the change in steady states. Notice that during the period 1975-1990, the volume of trade rises

[15] A gradual fall in τ seems to correspond to historical experience better. Governments tend to liberalize slowly over time, due probably to political reasons.

[16] The p-values for the standard t-tests, calculated using the Newey-West HAC estimator of the residuals' variance-covariance matrix, are almost zero. The adjusted R^2 is 0.88. The Jarque-Brera test generates a p-value equal to 0.11: the null hypothesis of normal distributed residuals cannot be rejected. Furthermore, the Breusch-Godfrey serial correlation LM test (two lags included) generates a p-value equal to 0.58 so that also the null hypothesis of serial uncorrelation cannot be rejected. Finally, the White F-test for heteroschedasticity (cross terms included) generates a p-value equal to 0.45: also the null hypothesis of homoschedasticity cannot be rejected.

in spite of τ being roughly constant. This is due to the divergence in relative factor endowments triggered by the liberalization process.

To show the extent to which the trade share in GDP is responding to the dynamics triggered by trade integration, Figure 7 also reports the predicted trade share in GDP when we keep factor endowments constant at their initial levels (dotted line). In this case, the response of the trade share to the fall in the trade cost is much weaker: the trade share in GDP rises by 0.04, whereas in the factor accumulation case it rises by almost three times as much. Figure 7 also reports the trade share predicted by the dynamic model under the assumption that the whole time path of τ is unexpected (dash-dotted line), *i.e.* when $\theta = 1$ in equation (19). Its qualitative behavior is quite similar to that obtained under $\hat{\theta} = 0.96$. The predicted time path of the export share generated with $\theta = 1$ also displays an increasing trend. The mechanism here is less powerful than above, given that the reduction in $\bar{\tau}$ is not anticipated by agents. However, the cumulative effect of the successive reductions in τ_t still applies.

Figure 8 revisits the relationship between the import tariff and the trade volume we explored in Figure 2, which we copy in the top-left panel of 8. The other three panels plot the results of our three simulations. Notice that the static model (bottom-right panel) displays a linear relationship between the import tariff and the trade share. Our dynamic model reproduces instead the non-linearity observed in the data. Again, the simulation under the assumption that the whole time path of the import tariff is known from the very beginning (top-right panel) produces a larger response than the simulation in which agents are assumed to learn slowly about the time path of the tariff (bottom-left panel).

5 Some Empirical Evidence

In our framework, the dynamics generated by the import tariff has a number of empirical implications. The large non-linear increase in the trade volume described above is probably the most striking one, and seems quite consistent with the empirical evidence. However, a careful examination of the impulse response functions reported in Figure 4 suggests that our model has another strong implication: the investment shares in income should *diverge* after episodes of trade liberalization. In particular, the investment share should increase in the capital-abundant country

	p-values (Wald stat.)			
Lags included:	1	2	3	4
$R_{RoW} \nrightarrow CW$	0.91	0.97	0.80	0.75
$CW \nrightarrow R_{RoW}$	0.03	0.00	0.00	0.00
$d(R_{RoW}) \nrightarrow d(CW)$	0.87	0.67	0.67	0.59
$d(CW) \nrightarrow d(R_{RoW})$	0.00	0.00	0.00	0.02

Table 1: Granger causality: investment-share ratio vs. tariff

and decrease in the labor-abundant one.[17]

Since comparable international data for GDP and its components are easily available, this prediction can be tested. We take advantage of the *Penn World Tables* Mark 6.1,[18] and collect data on real investment and GDP for a large set of countries (105 developed and developing countries, *i.e.* all countries whose sample starts in 1960) over the 1960-97 time horizon. In the spirit of our two-country model, we aggregate all countries but for the U.S. into a "rest of the world" entity, and calculate its aggregate investment share as total investment over total GDP.[19] Finally, we calculate the ratio of this aggregate investment share over the investment share of the U.S. computed similarly.

Our model predicts that decreases in the trade cost have a negative and persistent effect on the investment-share ratio, since the numerator decreases and the denominator increases. That is, the average tariff and the investment-share ratio should be positively correlated. Table 1 reports the p-values for a set of pairwise Granger causality Wald tests performed by running a VAR on the investment-share ratio R_{RoW} and the Clemens-Williamson average world tariff CW: the results suggest that we cannot reject the null hypothesis of the investment-share ratio not Granger causing the tariff, while the null hypothesis of the tariff not Granger causing the investment-share ratio can be rejected at high confidence levels. The result holds for a wide range of lags included, and remains valid if we switch to first differences. These results support the view that the average tariff helps forecast the current and future values of the investment-share ratio.

The previous analysis suggests that there exists a relationship between invest-

[17]More generally, the investment in each country's relatively abundant accumulable factor should increase. This result holds independently of the number of accumulable factors, while the result about income divergence does not, as already discussed in the text.

[18]See Heston, Summers and Aten [13]. We construct series for real investment and real GDP (in constant prices) using the variables RGDPL (real GDP per capita at constant prices, Laspeyres index), KI (investment share of RGDPL), and POP (population).

[19]Similar result are obtained if the cross-country average investment share is used.

Dependent variable: R_{RoW}										
			Lags of CW							
	c	$AR(1)$	0	-1	-2	-3	-4	$\bar{R}^2$	LM	WH
Value	0.58	-	4.56	-	-	-	-	0.45	-	-
p-value	*0.00*	-	*0.00*	-	-	-	-	-	*0.00*	*0.16*
Value	0.85	0.75	2.38	-	-	-	-	0.69	-	-
p-value	*0.00*	*0.00*	*0.07*	-	-	-	-	-	*0.45*	*0.60*
Value	1.30	0.90	-	-2.08	-	-	-	0.68	-	-
p-value	*0.00*	*0.00*	-	*0.42*	-	-	-	-	*0.63*	*0.99*
Value	0.63	0.61	-	-	4.02	-	-	0.69	-	-
p-value	*0.00*	*0.00*	-	-	*0.00*	-	-	-	*0.42*	*0.62*
Value	0.36	0.42	-	-	-	5.98	-	0.74	-	-
p-value	*0.00*	*0.00*	-	-	-	*0.00*	-	-	*0.50*	*0.42*
Value	0.26	0.24	-	-	-	-	6.64	0.73	-	-
p-value	*0.05*	*0.07*	-	-	-	-	*0.00*	-	*0.20*	*0.30*

Table 2: Regressions

ment rates and tariffs, but does not clarify the actual sign of this relationship. To address this issue, we compute the impulse response functions of the endogenous variable, the investment-share ratio, when the exogenous variable, the average tariff, is hit by a shock. Figure 9 shows the impulse response of R_{RoW} after a one standard deviation shock to CW under an orthogonal Cholesky identification scheme in which the CW is placed first in the variables' ordering. In other words, it plots the response of the investment-share ratio to a positive shock to the average tariff, under the assumption that shocks to the average tariff contemporaneously affect the latter only. As we can see, a positive shock to the average tariff has a significantly positive effect on the investment-share ratio.

Another natural step forward is to regress the investment-share ratio on a constant and the average tariff: Table 2 reports the results for this and some other experiments.[20] The coefficient on the contemporaneous tariff is positive and significant,[21] and the adjusted R^2 is quite high. However, the usual tests on the residuals (the Breusch-Godfrey Serial Correlation Test, LM, and the White Heteroskedasticity Test, WH) suggest that the residuals are not *iid*, and in particular that they are plagued wtih a strong autocorrelation.

[20] Note that theoretical considerations rule out the possibility that our variables are integrated or trend stationary. We expect both the average tariff and the investment-share ratio to converge to a constant value in the long run.

[21] The p-values for all standard tests are constructed using the Newey-West *Heteroskedasticity and Autocorrelation Consistent* (HAC} estimator for the residuals' covariance matrix.

To take this into account, we add an autoregressive component to the regression: this effectively solves the autocorrelation in the residuals problem, and increases the explanatory power of the regression, as measured by the adjusted R^2. Note that the coefficient on the average tariff remains positive and significant at the 10% level. Including an autoregressive component in the regression has also a straightforward economic interpretation: if some of the countries in the sample are actually not in steady state at the beginning of the sample period, we should expect an adjustment process due to the standard neoclassical conditional convergence argument, that drives the investment-share ratio down to its long-run value. This long-run adjustment process would be captured by the autoregressive component in our regression. The model predicts that the effect of a reduction in the trade cost should persist over time: Table 2 reports the results for regressions that include various lags of the average tariff. With the only exception of the first lag, all coefficients are positive and highly significant, and their size increases with the lag itself.

6 Concluding Remarks

The standard static trade model cannot produce a large effect of trade liberalization on the volume of trade without unrealistically high elasticities of substitution. However, a dynamic version of the same model (with unitary elasticities) is enough to achieve this goal. Our model is very stylized in a number of ways (just two countries, only one accumulable factor, no technical differences across countries, no technical progress, no intra-industry trade,...), and encourages extensions in several directions to better understand the growth of world trade and the dynamics of particular countries.

References

[1] Baier, S.L. and J.H. Bergstrand (2001): "The Growth of World Trade: Tariffs, Transport Costs, and Income Similarity," *Journal of International Economics*, 53, 1-27.

[2] Bergoeing, R. and T.J. Kehoe (2001): "Trade Theory and Trade Facts," Federal Reserve Bank of Minneapolis, Research Department Staff Report 284.

[3] Clemens, M.A. and J.G. Williamson (2002): "Why Did the Tariff-Growth Correlation Reverse after 1950?" NBER WP 9181.

[4] Cooley, T. and E. Prescott (1995): "Economic Growth and Business Cycles," in T. Cooley, ed., *Frontiers of Business Cycle Research*, Princeton Univ. Press, Princeton, 1-38.

[5] Cuñat, A. and M. Maffezzoli (2002): "Neoclassical Growth and Commodity Trade," CEPR Discussion Paper 3322.

[6] Davis, D.R. and D.E. Weinstein (2001a): "An Account of Global Factor Trade," *American Economic Review,* 91, 1423-1453.

[7] Davis, D.R. and D.E. Weinstein (2001b): "Do Factor Endowments Matter for North-North Trade?" NBER WP 8516.

[8] Davis, D.R. and D.E. Weinstein (2001c): "The Factor Content of Trade," NBER WP 8637.

[9] Dornbusch, R., S. Fischer, and P.A. Samuelson (1977): "Comparative Advantage, Trade, and Payments in a Ricardian Model with a Continuum of Goods," *American Economic Review,* 67, 823-839.

[10] Dornbusch, R., S. Fischer, and P.A. Samuelson (1980): "Heckscher-Ohlin Trade Theory With a Continuum of Goods," *Quarterly Journal of Economics*, 95, 203-224.

[11] Helpman, E. (1987): "Imperfect Competition and International Trade: Evidence from Fourteen Industrial Countries," *Journal of the Japanese and International Economies*, 1, 62-81.

[12] Helpman, E. and P.R. Krugman (1985): *Market Structure and Foreign Trade*, MIT Press.

[13] Heston, Alan, R. Summers and B. Aten, (2002): *Penn World Table Version 6.1*, Center for International Comparisons at the University of Pennsylvania (CICUP), December.

[14] Hummels, D. and J. Levinsohn (1995): "Monopolistic Competition and International Trade: Reconsidering the Evidence," *Quarterly Journal of Economics*, 110, 799-836.

[15] Judd, K.L. (1992): "Projection Methods for Solving Aggregate Growth Models", *Journal of Economic Theory*, 58, 410-52.

[16] Kehoe, T.J. and K.J. Ruhl (2002): "How Important is the New Goods Margin in International Trade?" mimeo, University of Minnesota.

[17] Markusen, J.R. (1986): "Explaining the Volume of Trade: An Eclectic Approach," *American Economic Review*, 76, 1002-1011.

[18] Mundell, R.A. (1957): "International Trade and Factor Mobility," *American Economic Review*, 47, 321-335.

[19] Romalis, J. (2001): "Factor Proportions and the Structure of Commodity Trade," mimeo, Chicago GSB.

[20] Samuelson, P.A. (1954): "The Transfer Problem and Transport Costs: Analysis of Effects of Trade Impediments," *Economic Journal*, 64, 264-289.

[21] Stiglitz, J.E. (1970): "Factor Price Equalization in a Dynamic Economy," *Journal of Political Economy*, 101, 961-987.

[22] Ventura, J. (1997): "Growth and Interdependence," *Quarterly Journal of Economics*, 112, 57-84.

[23] Yi, K.-M. (2003): "Can Vertical Specialization Explain the Growth of World Trade?" *Journal of Political Economy*, 111, 52-102.

7 Appendix

Following Judd [15], we approximate the policy functions for consumption over a rectangle $D \equiv [\underline{k}, \overline{k}] \times [\underline{k}, \overline{k}] \in R_+^2$ with a linear combination of multidimensional orthogonal basis functions taken from a *2*-fold tensor product of Chebyshev polynomials. In other words, we approximate the policy function for country $j \in \{H, F\}$ with:

$$\widehat{c}_j(K_H, K_F; \mathbf{a}_j) = \sum_{z=0}^{d}\sum_{q=0}^{d} a_{zq}^j \psi_{zq}(K_H, K_F) \tag{20}$$

where:

$$\psi_{zq}(K_H, K_F) \equiv T_z\left(2\frac{K_H - \underline{k}}{\overline{k} - \underline{k}} - 1\right) T_q\left(2\frac{K_F - \underline{k}}{\overline{k} - \underline{k}} - 1\right) \tag{21}$$

and $\{K_H, K_F\} \in D$. Each T_n represents an n-order Chebyshev polynomial, defined over $[-1, 1]$ as $T_n(x) = \cos(n \arccos x)$, while d denotes the higher polynomial order used in our approximation. In our case, it turns out that $d = 4$ is a good compromise between speed and accuracy.

We defined the residual functions as:

$$R_j(k_H, k_F; \mathbf{a}_j) \equiv \beta\hat{c}_j(k_H, k_F; \mathbf{a}_j)\left(r_j'/P_j' + 1 - \delta\right) - \hat{c}_j(k_H', k_F'; \mathbf{a}_j) \tag{22}$$

where $k_j' = w_j/P_j + (1 - \delta + r_j/P_j)\, k_j - \hat{c}_j(k_H, k_F; \mathbf{a}_j)$; the factor prices in terms of the final goods are determined by numerically solving the appropriate equilibrium conditions.

To pin down the vectors $\mathbf{a}_j$ we use the simplest projection method: orthogonal collocation. This method identifies the $2m^2$ coefficients, where $m = d+1$, by making the approximating polynomials exactly solve the functional equations (22) at some m^2 distinct points in D, known as collocation nodes. In other words, the functional equations are transformed into a system of $2m^2$ non-linear equations:

$$R_j(k_{zH}, k_{qF}; \mathbf{a}_j) = 0, \quad z, q = 1, 2, ..., d+1 \tag{23}$$

that can be solved with any robust numerical solver.[22] To minimize the approximation error, we optimally chose the collocation nodes among the zeros of Chebyshev polynomials: given the m zeros of $T_m\left[2(x - \underline{k})/\left(\overline{k} - \underline{k}\right) - 1\right]$ in $\left[\underline{k}, \overline{k}\right]$, we organize them into two (identical) vectors $\{k_{H,i}\}_{i=1}^m$and $\{k_{F,i}\}_{i=1}^m$ and take their Cartesian product $\{k_{H,i}\} \times \{k_{F,i}\}$ as the set of our collocation nodes.

Table 3 summarizes the empirical distribution of the Euler equation residuals in absolute terms, i.e. the values of $|R_j(k_H, k_F, \mathbf{a}_j)|$, over 100 *equally spaced* points in D that do obviously not coincide with the collocation nodes. As we can see, the size

[22]We use Broyden's variant of the standard Newton method and follow a continuation approach to obtain the initial conditions.

	Home	Foreign
Avg.	4.40e-11	1.77e-10
Med.	4.56e-11	2.07e-10
Std.	4.80e-11	1.96e-10
Max.	8.74e-11	3.07e-10

Table 3: Euler equation residuals

of the residuals is extremely small, and this confirms that orthogonal collocation is not only simple but also surprisingly efficient and accurate. The functional equation residuals are of course only an indirect measure of the quality of our approximation, but still a very informative one. Another informative test of the approximation accuracy is the long-run stability of the solution: the approximated system remains in steady state even if the simulation horizon is extended to $10,000$ years.

Once the approximated policy functions are available, we choose the initial conditions and simulate the system recursively to generate the artificial time series for all variables of interest by using the appropriate set of policy functions.

Figure 1: Average import tariff and US GDP share of volume of trade. (Time paths)

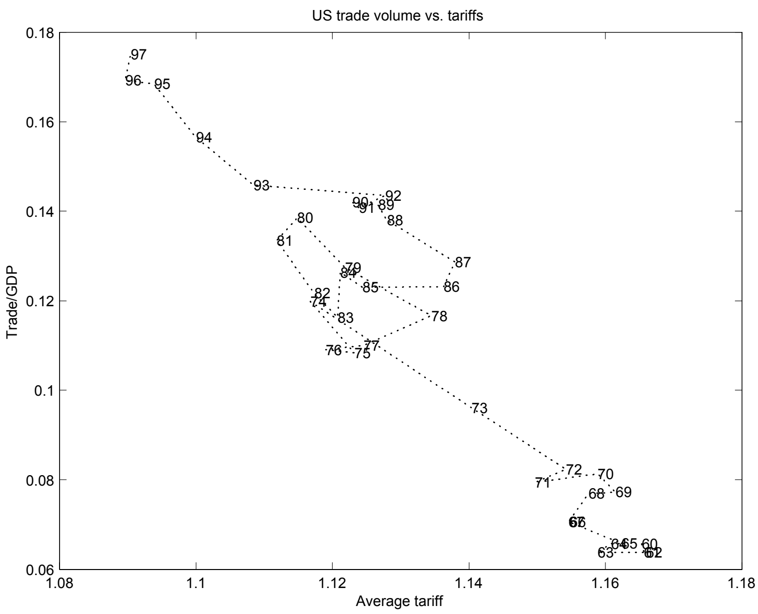

Figure 2: Average import tariff and US GDP share of volume of trade.

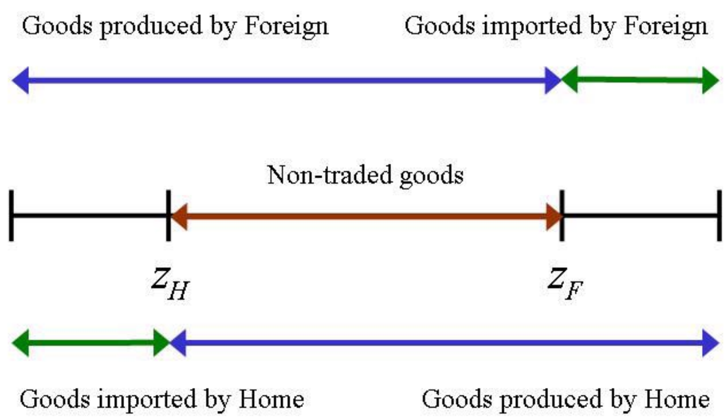

Figure 3: Equilibrium trade pattern

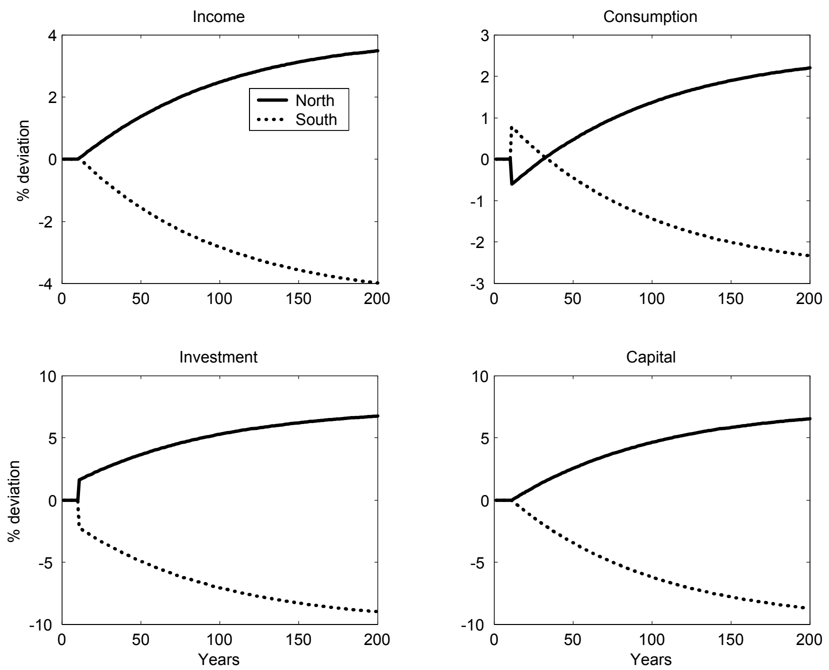

Figure 4: Income, consumption, investment, and capital.

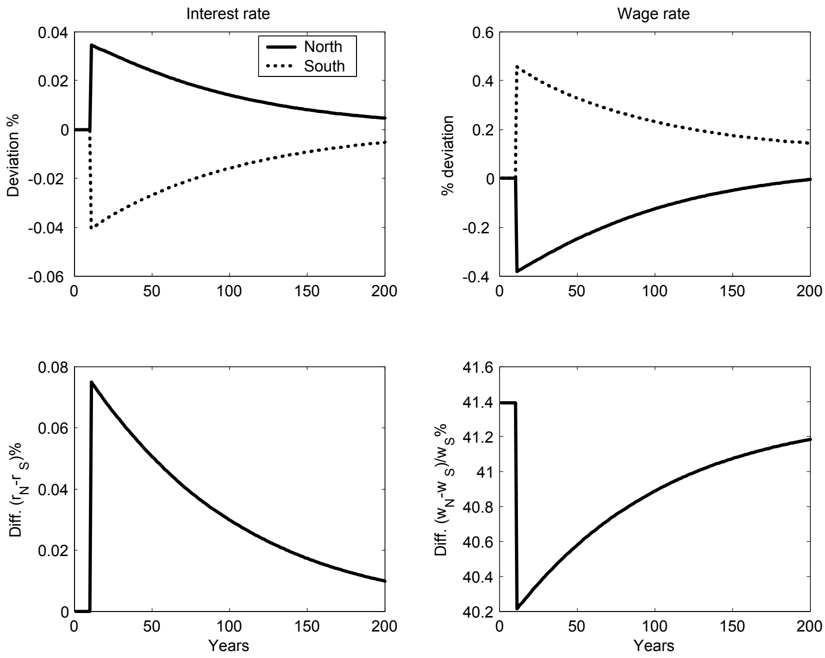

Figure 5: Factor prices (deviations and differentials).

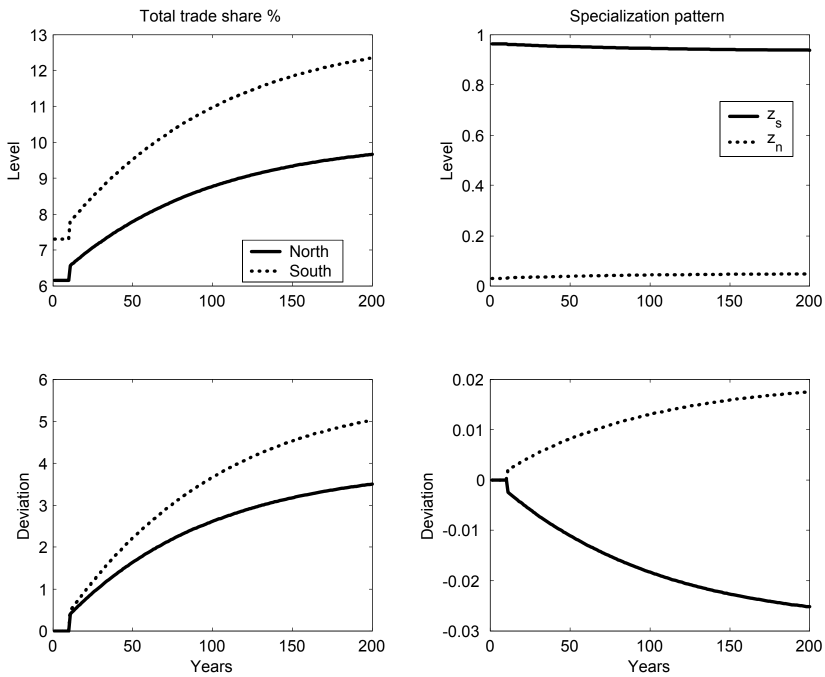

Figure 6: Trade shares and specialization (levels and deviations).

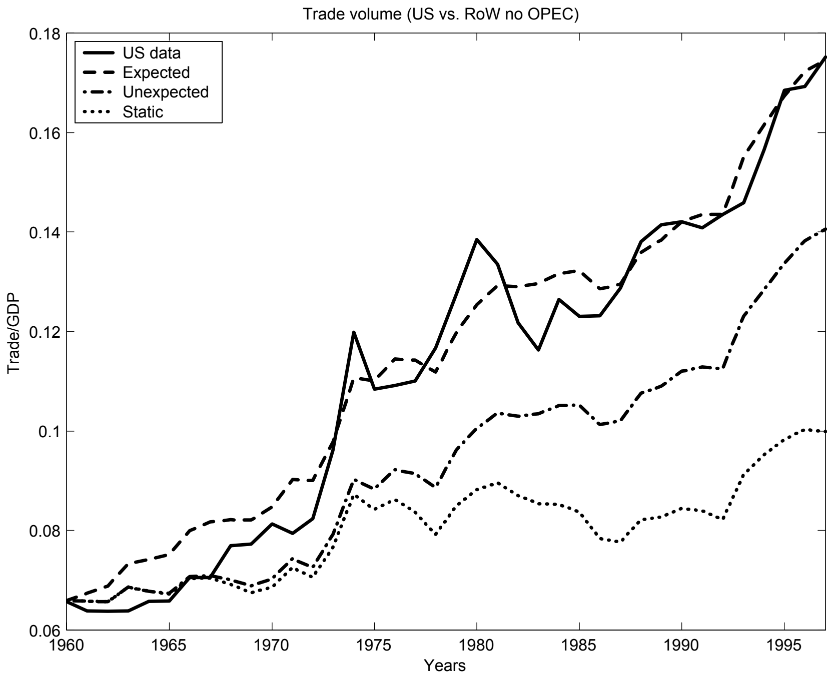

Figure 7: Trade integration and the US trade share. (1)

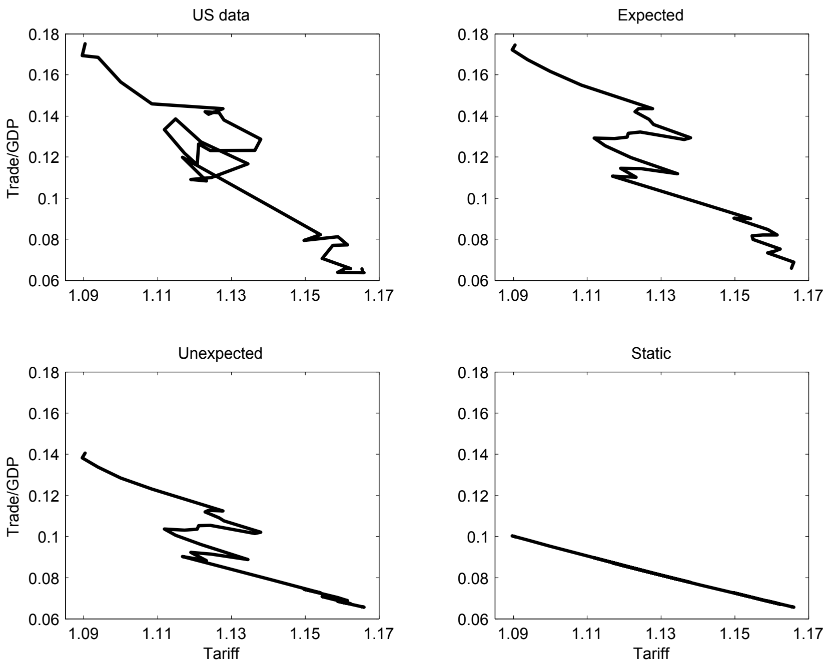

Figure 8: Trade integration and the US trade share. (2)

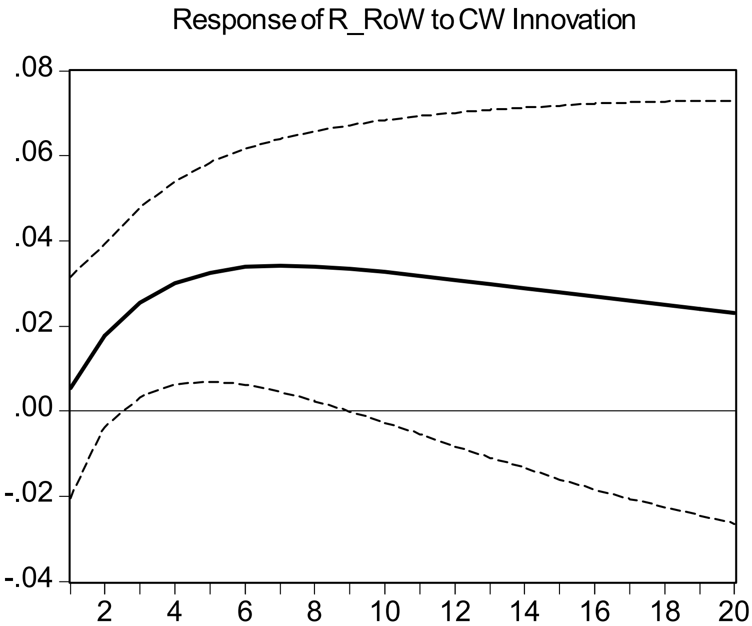

Figure 9: VAR(1) impulse response function (Cholesky identification scheme)